

Mechanism of Thermal Comfort and Its Application in Indoor Environment

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Abstract: The reaction of thermoregulation systems in animal experiments was studied. By measuring the levels of dopamine in rats, we found that the rats' thermal neutral zone ranges from 27°C to 28°C. Similarly, there is also a thermal neutral zone in the thermoregulated center of humans. Based on a long-term survey in Shanghai, the neutral temperature for occupants was determined and the relationship between neutral temperature and relative humidity was studied.

Key words: thermal comfort; thermoregulation; thermal neutral zone; adaptive model

1. INTRODUCTION

Today, people pay more and more attention to energy, environment and health. Building more comfortable and healthful thermal environment is the trend of thermal comfort research. Although most of air-conditioning environment confirm to the rule and standard, many people still complain about that. Moreover, scholars are also doubtful whether there is only a unique thermal comfort standard all over the world. They think that in the same environment thermal sensation might be different for reasons of race, job, climate, etc. How does environmental temperature influence thermal balance and thermal sensation of human? Is thermal neutral temperature zone existed and is it reasonable?

In this paper, we attempted to explain the mechanism of thermal comfort from medicinal point. With animal experiment, the reaction of thermoregulation system when environmental temperature changed was studied. According to the

results, thermal environment and adaptive model in shanghai was studied based on human thermal comfort surveys.

2. ANIMAL EXPERIMENT ON THERMOREGULATION SYSTEM

Experiments have shown that dopamine DA and its receptors take an important part in thermoregulation of animals ^[1]. Frequency of discharges of warm and cold sensitive neuron in PO/AH may be related to the level of DA. Some studies have proved that DA could restrain the activity of cold sensitive neuron and decrease the quantity of heat production ^[2,3]. On the other side, it could strengthen the activity of warm sensitive neuron and increase elimination of heat. For example, with heat load, the model of thermoregulation under DA controlling is shown in Fig.1 ^[4]. Therefore, observing the change of metabolite of dopamine (DA) and rectal temperature can be used to study the reaction of thermoregulation system in different temperature.

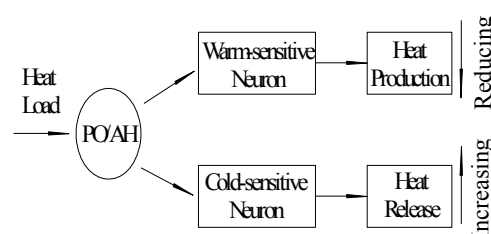


Fig. 1 The model of thermoregulation under DA controlling

2.1 Materials and Methods

The experiments were performed on 28 rats of both sexes weighing 200-300g. The animals were anesthetized with 1% mebumal sodium (40mg/kg). Supplemental doses of anesthetics were given when required. The animal was fixed on a stereotaxic frame, as shown in Fig.2. Recording electrode was inserted into the POAH (Stereotaxic coordinates: AP0.7, RL1.5, H8.5). Reference electrodes (Ag/AgCl) and pair electrodes (platinum filament) were placed in a position of epidural. The prepare and disposal of the electrodes refer to other experiments [5,6]. The environmental relative humidity was maintained at 60-70% and air velocity was maintained at 0.2m/s during the experiment. The range of ambient temperature is from 16°C to 34°C. We measured the peak value of electric current of metabolite of dopamine (3,4-dihydroxyphenylacetic acid, DOPAC) in PO/AH with the method of in vivo Differential Pulse Voltammetry (DPV), and recorded data every ten minutes during the experiment. Rectal temperature was measured by copper-constantan thermocouple (0.2mm), which was connected with Keithley 2700 data collector. Data was input into computer by line R232 synchronously. At the end of experiment, location of recording was identified by optical microscope and data from those electrode tips not in the desired area were excluded.

On the base of analysis and comparison of data, the peak value of DOPAC and rectal temperature at 28°C was taken as reference point. By which, the percentage of others peak value of DOPAC could be shown clearly. Data were expressed as $\bar{x} \pm s$ and analyzed using paired Students T test. Differences were considered statistically significant as $P < 0.05$.

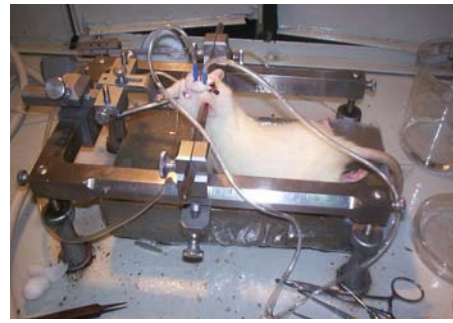


Fig.2 Rat is fixed on the orientation device

2.2 Results

2.2.1 Peak Value of DOPAC

The results show that the changes of ambient temperature resulted in the fluctuation of DOPAC. Since the level of DOPAC kept nearly invariant ($P > 0.05$) when ambient temperature was 28°C ($n=6$), which was shown in Table 1.

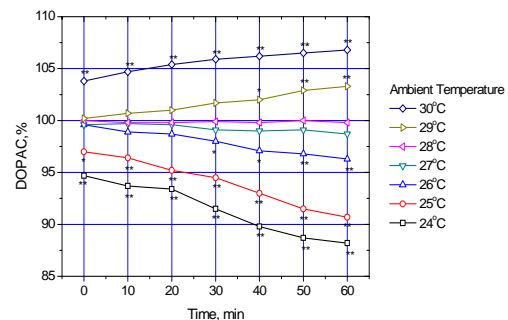


Fig.3 Effects of ambient temperature on the level of DOPAC (* $P < 0.05$, ** $P < 0.01$)

As shown on Fig.3, ambient temperature had effect on the level of DOPAC of rats.

- When the ambient temperature was 28°C, the level of DOPAC kept stable during the testing time lasting 1 hour ($P > 0.05$).
- When the ambient temperature was above 28°C, the longer of testing time lasted, the higher of level of DOPAC was. There were significant difference ($P < 0.05$) between the level of DOPAC at 28°C and at 29°C.

Tab.1 The level of DOPAC when ambient temperature is 28 °C

Time, min	0	10	20	30
Level of DOPAC, %	99.72±0.93	99.75±1.04	99.85±1.30	100.07±1.25
Time, min	40	50	60	
Level of DOPAC, %	99.82±1.01	100.07±1.26	99.92±1.01	

Tab.2 Rectal Temperature when ambient Temp is 28 °C

Time, min	0	10	20	30
Rectal temperature, °C	31.85±1.36	31.87±1.36	31.87±1.49	31.85±1.53
Time, min	40	50	60	
Rectal temperature, °C	31.86±1.51	31.87±1.48	31.91±1.49	

- When the ambient temperature was below 28°C, the longer of testing time lasted, the lower of level of DOPAC was. The level of DOPAC decreased during the testing time insignificantly ($P>0.05$). When the ambient temperature was 26°C, the level of DOPAC decreased significantly ($P<0.05$) and reached 98.0% 30 minutes later. When the ambient temperature was 25°C and 24°C, the level of DOPAC reached 97.0% and 94.7% respectively, and increased significantly ($P<0.05$) after testing.

It is obvious that it almost had no effect on thermoregulation system of rats when ambient temperature was 27°C or 28°C and the level of DOPAC kept stable. Contrarily, the level of DOPAC changed obviously when temperature deviated from 27°C or 28°C. So ambient temperature affected thermoregulation system of rats and the later adapted environmental change with corresponding reaction.

2.2.2 Rectal temperature

As was proved by the experiment, ambient temperature also affected rectal temperature of rats. When the ambient temperature was 28°C ($n=6$), rectal temperature of rats maintained unconverted during testing ($P>0.05$), which is shown in Table2. Therefore, rectal temperature of rats at 28°C was taken as check sample.

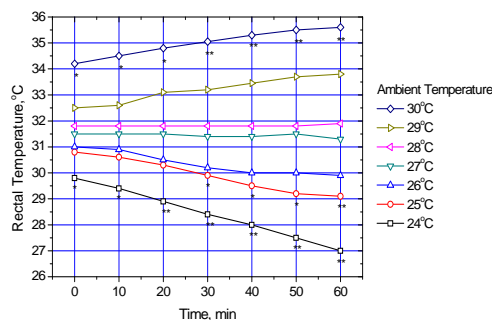


Fig.4 Effects of ambient temperature on rectal temperature (* $P<0.05$, ** $P<0.01$)

As was shown in Fig.4, ambient temperature also had effect on rectal temperature of rats.

- During testing while ambient temperature maintained 28°C, the rectal temperature of rats

kept stationary, which was $31.8^{\circ}\text{C}\pm 1.46$ and $P>0.05$. The change tendency of rectal temperature of rats at 27°C was similar to it at 28°C, which was $31.5^{\circ}\text{C}\pm 1.38$ and $P>0.05$.

- There had been a gradual decrease in the rectal temperature of rats while ambient temperature was below 28°C. After 30 minutes, the rectal temperature of rats was gradual decreasing and reached 29.9°C when ambient temperature was 25°C. However, the change was insignificant, $P>0.05$, but the rectal temperature of rats quickly decreased ($P<0.05$) during testing and reached 29.8°C at most.
- There had been a gradual increase in the rectal temperature of rats while ambient temperature was above 28°C. After 20 minutes, the rectal temperature of rats was gradual rising and reached 33.1°C when ambient temperature was 29°C. The change was insignificant, $P>0.05$. When ambient temperature was 30°C, rectal temperature of rats was quickly risen ($P<0.05$) during testing and reached 35.6°C at most.

As was analyzed above, there was a neutral temperature zone in which thermoregulation system of rats was hardly influenced by ambient temperature. In other words, the rectal temperature of rats kept almost invariant in the neutral temperature zone.

2.3 Discussion

As the result of experiments showed, the level of DOPAC corresponds changed to adapt the alternative of the environmental temperature. The level of DOPAC decreased obviously when the environmental temperature cooling down and it could increase when the environmental temperature warming up. Some studies also researched the alternative of level of DA of rats in cold environment. Sun found that the level of DA would decrease obviously and always keep a low level when rats stayed in cold environment (5°C) for 21 days [7]. In this study, we can get the conclusion on the experiment that when

environmental temperature is 27°C or 28°C it's not obviously of the reaction of thermoregulation system of rats to the changing of environment. When the ambient temperature deviated from 27°C or 28°C, the reaction of thermoregulation system to environmental temperature was very markedly and became strength with rising or decreasing of temperature.

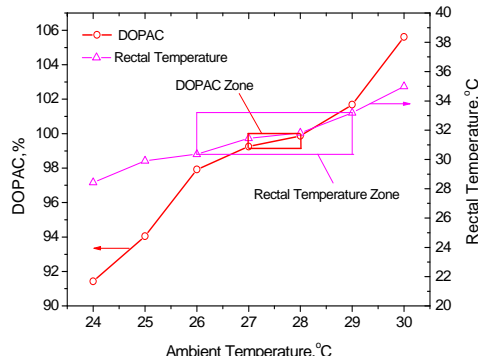


Fig.5 The no-reaction zone of DOPAC and Rectal temperature

It is clearly that the environmental temperature can not trigger physiological responses that maintain thermal homeostasis when it is suitable. Based on the above analysis on the changing tendency of the DOPAC and rectal temperature of rats, it's obviously that the change of DOPAC of rats reacted quickly when the environmental temperature changed, but that of rectal temperature alternated slowly. To the change of DOPAC, it is no statistically significant when environmental temperature is in the range from 27°C to 28°C. To the change of rectal temperature, however, the temperature zone is from 26°C to 29°C. It is shown in Fig.5. The no-reaction zone of rectal temperature is wider than that of DOPAC. That means there is a lag between the change of the level of DOPAC and rectal temperature. When environmental temperature deviated from 27°C or 28°C slightly, such as 26°C or 29°C, the

thermoregulation system started to work and adapt the alternative of temperature. As consequence, the level of DAPOC of rats changed quickly because of the activity of DA strengthens. However, the changes of rectal temperature of rats appeared lag obviously, which stated to change 20-30 minutes later. When environmental temperature is below 25°C or above 30°C the DOPAC and rectal temperature of rats both changed quickly and obviously. Commonly saying, the level of DOPAC and rectal temperature of rats changed correspondingly when the environmental temperature alternated.

Similar to rats, human also adjusted body temperature by the way of autonomic nervous-regulate and action-regulate. The physiological reaction of human, such as level of DAPAC and rectal temperature, should be similar to those of rats when the environmental temperature was changed. That is to say, there is a thermal neutral temperature zone in the thermoregulator center of human, which can adapt itself according to the change of environmental temperature.

3. STUDY ON THE THERMAL ENVIRONMENT IN SHANGHAI

In section2, it can be inferred reasonably that there is a thermal neutral temperature zone in the thermoregulator center of human. In this section, based on human thermal comfort surveys in existing residential buildings in Shanghai, the neutral temperature for occupants was determined and the relationship between neutral temperature and relative humidity was studied.

Tab.3 Location of measurement point and accuracy

Parameter	Location (m)	Accuracy	ASHRAE or ISO Standard	Measurement Instrument
Air Temperature	0.1, 0.6, 1.1	± 0.2 □ (-25~+75 □)	± 0.2 □	TESTO 110
Air Velocity	0.1, 0.6, 1.1	$\pm 2\%$ m.v.	± 0.05 m/s	EY3-2A
Relative Humidity	1.1	± 0.5 □	± 0.5 □	WS508D
Mean Radiant Temperature	1.1	± 0.1 □	± 0.2 □	150 mm black-bulb

3.1 Methods and Background Descriptions

3.1.1 Instruments

Air temperature, globe temperature, air velocity and relative humidity were measured in this study. The locations of measurements were conducted at representative points in the building. The measurement instrument and height is shown in Table 3. The accuracy of the instrument followed that prescribed in ASHRAE Standard 55-1992 [8] and ISO 7726 [9]. Measurements of the environmental data were taken while the subjects were completing their questionnaires.

3.1.2 Questionnaire

The long-term field investigation was carried out in 5 natural ventilated residential buildings in Shanghai from April 2003 to November 2004. Total of 1768 returned questionnaire were collected in the study. The questionnaire was divided into two parts, environmental parameters and sensation vote. The background included demography and health. The sensation vote questionnaire mainly included thermal sensation, indoor air quality and personal comfort. The scope and format of the questionnaire was based on a standardized questionnaire [10,11].

3.1.3 Background Data

The subjects were between 18 to 42 years old having an average age of 28.7 years, with standard deviation of 6.4 years. The shortest subject was 158 cm and the tallest one was 184 cm, with a mean height of 171.6 cm and standard deviation of 5.3 cm. They were in good health. Subjects in the study could freely adjust their clothing according to the changes in mean indoor temperature.

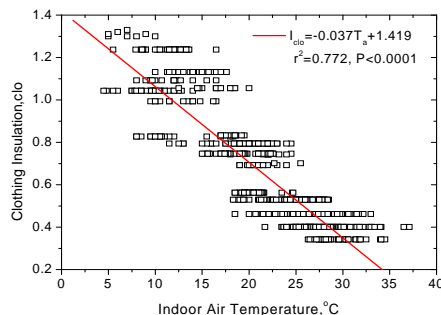


Fig.7 Change of clothing insulation with temperature in Shanghai

3.2.3 Indoor Air Velocity

The change of indoor air velocity is small in this investigate and the proportion of indoor air velocity

of climate. Metabolic rates and clothing insulation were estimated in accordance with ASHRAE Standard 55-1992. Metabolic rates of the subjects are estimated to be, on average, 1.2 met (70 W/m²).

3.2 Results and Discussions

3.2.1 Outdoor Climatic Data

The outdoor weather data for the period of survey was obtained from National Meteorological Information Centre of China. The monthly mean outdoor temperature in 2003 and 2004 is shown in Fig.6. The maximum mean temperature in 2003 is 33.7°C T_a and that in 2004 is 34.2°C T_a .

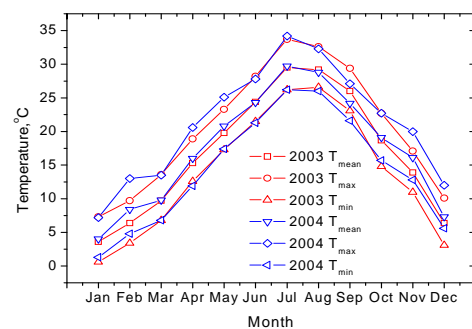


Fig.6 Outdoor temperature of shanghai in 2003 and 2004

3.2.2 Clothing Insulation

Mean clothing insulation values varies seasonally in resident buildings. The range of mean value is between 0.35 and 1.35 clo in naturally ventilated buildings.

The clothing pattern of subjects has a stronger correlate with indoor temperature. Fig.7 shows that with mean clothing insulation decreasing by average of 0.1 clo for every 2.7°C increase

less than 0.5 m/s is more than 95% (95.2%), as described in ASHRAE standard 55. The regressed equation of indoor air velocity against operative temperature (T_{op}) is,

$$v = 0.02 \times T_{op} - 0.25, \quad r^2 = 0.39 \quad (1)$$

3.2.4 Relative Humidity

The mean outdoor annual relative humidity is 74% in 2003 and that is 70% in 2004. The range of monthly mean indoor relative humidity is between 50% and 70%. Fig.8 gives the correlation between thermal sensation votes (TSV) against indoor mean operative temperature in Shanghai with different humidity. The neutral temperature in Shanghai changes a little when relative humidity rang between

50% and 70%. The neutral temperature in Shanghai is $22.4 \pm T_{op}$, $21.5 \pm T_{op}$, $22.9 \pm T_{op}$, $22.8 \pm T_{op}$ and $22.7 \pm T_{op}$ when relative humidity is 45%, 50%, 55%, 65% and 72% respectively. And they are much closed to the annual neutral temperature $22.5 \pm T_{op}$ (see section 2.2.5).

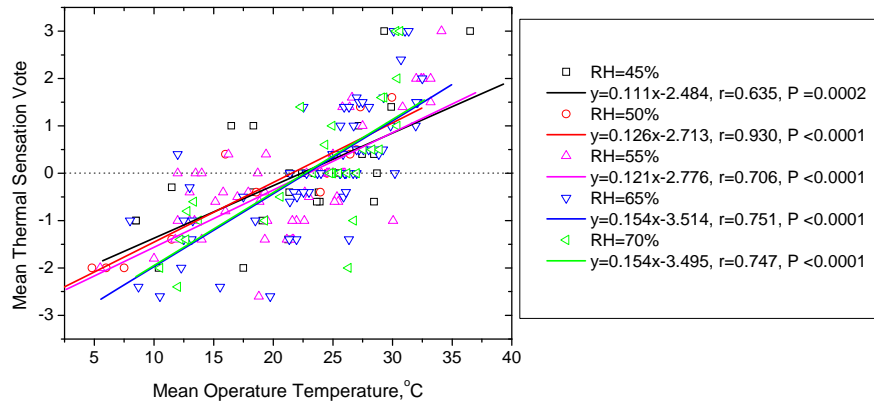


Fig.8 The relationship between thermal comfort vote in different humidity in Shanghai

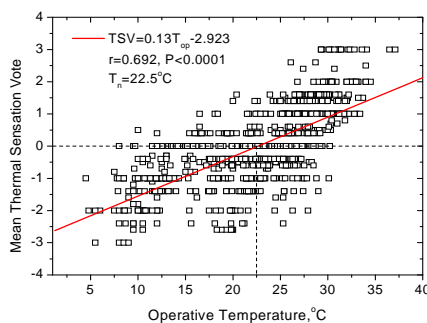


Fig.9 Indoor thermal sensation vote and operative temperature in Shanghai

For naturally ventilated buildings, the correlation between TSV against T_{op} in Shanghai is given by Eq.2.

$$TSV = 0.130 \times T_{op} - 2.923 \quad (2)$$

The annual neutral temperature for naturally ventilated building in Shanghai is $22.5 \pm T_{op}$ in 2003 and 2004. The slope of the regression line of Shanghai is small. Eq.2 suggests that occupants in Shanghai are more tolerant of a wider range of temperatures, as compared to occupants in other studies [12,13].

4. CONCLUSIONS

(1) The thermoregulation system of rats starts to work to maintain the normal body temperature in different environmental temperature. The level of metabolite of DA (DOPAC) and rectal

3.2.5 Thermal sensation

Fig.9 demonstrates the influence of indoor mean operative temperature on thermal sensation vote. The range of accepted temperature in Shanghai is between $14.7 \pm T_{op}$ and $29.8 \pm T_{op}$. The result is similar to other researches.

- temperature are variant when rats in different environmental temperature;
- (2) The level of DOPAC has inflection point when environmental temperature changes;
- (3) Similarly to DOPAC, the changing tendency of rectal temperature of rats is corresponded with environmental temperature;
- (4) There is a thermal neutral temperature zone in the thermoregulator center of human, which could adapt itself according to the change of environmental temperature;
- (5) With the long-term survey, the annual neutral temperature for naturally ventilated building in Shanghai is $22.5 \pm T_{op}$ in 2003 and 2004. The range of accepted temperature in Shanghai is between $14.7 \pm T_{op}$ and $29.8 \pm T_{op}$.

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